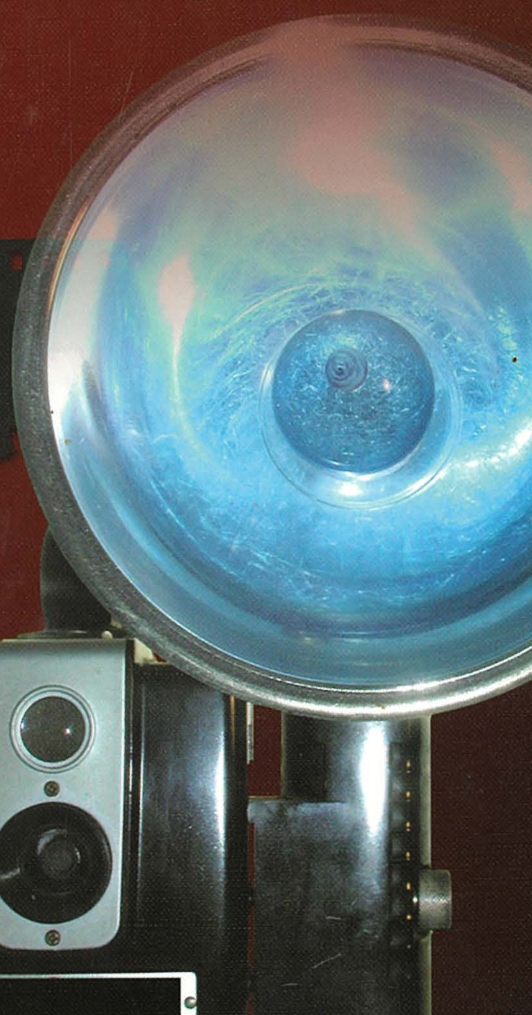
EXHIBIT H

Camera Lenses

From Box Camera to Digital

Gregory Hallock Smith



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SPIE
PRESS
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Smith, Gregory Hallock.
Camera lenses : from box camera to digital / Gregory Hallock Smith.
p. cm.
Includes bibliographical references and index.
I. Photographic lenses. I. Title.
TR270.S654 2006
771.3'52--dc22

2005033987

ISBN: 0-8194-6093-1

Published by

SPIE—The International Society for Optical Engineering
P.O. Box 10
Bellingham, Washington 98227-0010 USA
Phone: +1 360 676 3290
Fax: +1 360 647 1445
Email: spie@spie.org
Web: http://spie.org

Printed in the United States of America.

The International Society for Optical Engineering

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Part A Concepts and Techniques

as much as the fore-and-aft departure of the sagittal surface. These three surfaces are illustrated in Figs. 8.4(a) and 8.4(b). Astigmatism can therefore be used to artificially flatten the field in some systems that unavoidably have a sizable Petzval sum. Examples are the Landscape lens, the Rapid Rectilinear lens, and most eyepieces.

8.3 Effective Focal Length and Back Focal Length

Two lens parameters of crucial importance are the effective focal length and the back focal length. The back focal length (or simply the back-focus) is the rear clearance between the lens and the image.

The effective focal length (EFL) determines the image scale, or how big the image is. The back focal length (BFL) determines where the image is located relative to the mechanical lens.

To illustrate the concepts of effective focal length and back focal length, consider the telephoto and retrofocus lens types.

Contrary to much popular usage, a telephoto lens is not merely a lens having a relatively long focal length and narrow field of view. A true telephoto lens has negative power in its rear section to create a more compact and convenient system whose physical length is shorter than its EFL. This unsymmetrical configuration is shown in Fig. 8.5. Note that the rear negative element causes the chief ray to increase its outward divergence, thus increasing image size. Astronomers use this same telephoto principle when they add a negative Barlow lens in front of focus to increase the focal length of their telescopes.

Conversely, a retrofocus lens (originally a trade name by Angénieux) is a backwards telephoto with negative power in front to create a system whose BFL

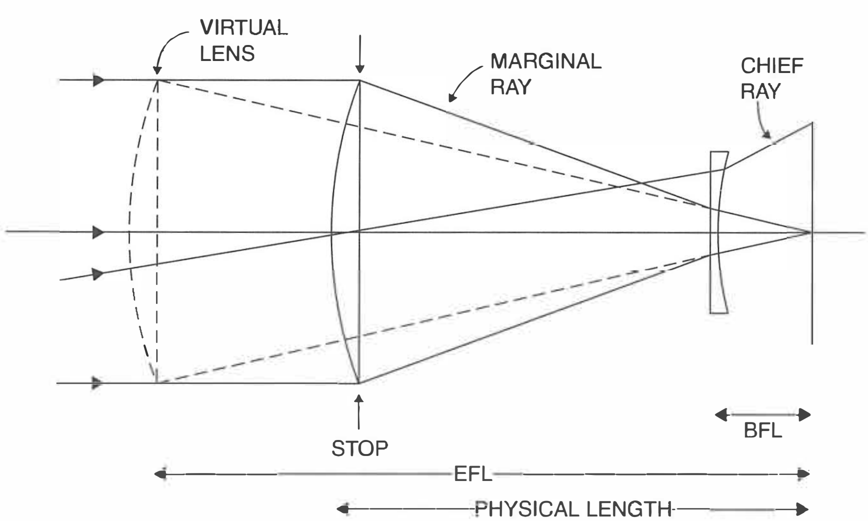

Figure 8.5 Telephoto lens. From *Practical Computer-Aided Lens Design* published by Willmann-Bell, Inc. (www.willbell.com) Used with permission.

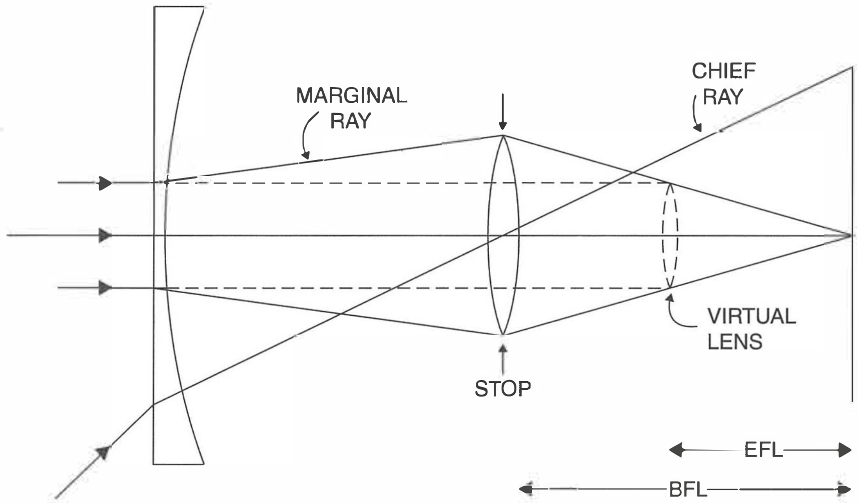

Figure 8.6 Retrofocus lens. From *Practical Computer-Aided Lens Design* published by Willmann-Bell, Inc. (www.willbell.com) Used with permission.

is greater than its EFL. This unsymmetrical configuration is shown in Fig. 8.6. The retrofocus principle is most often used in wide-angle lenses that must provide extra clearance for a single-lens-reflex mirror. Retrofocus lenses are big and bulky for their focal length, but because wide-angle lenses have short focal lengths, this relatively large size is still practical. Note in Fig. 8.6 that the front negative element reduces the chief ray angle both inside the lens and on the image, thus allowing the rear part of the wide-angle lens to work with an effectively narrower field of view.

8.4 Aberrations in Terms of BFL and EFL

For a lens and a distant object, much insight can be gained about the basic seven aberrations by analyzing how BFL and EFL change (1) with wavelength, (2) with pupil zone height, and (3) with field zone height.

For BFL:

A change in BFL with wavelength causes longitudinal chromatic aberration,
A change in BFL with pupil zone causes spherical aberration, and
A change in BFL with field zone causes astigmatism and field curvature, that is, tangential and sagittal field curvature.

Similarly for EFL:

A change in EFL with wavelength causes lateral chromatic aberration,
A change in EFL with pupil zone causes coma, and
A change in EFL with field zone causes distortion.

Chapter 21

Wide-Angle Lenses

So far we have looked at standard or normal lenses for large-format cameras. A normal lens has a focal length roughly equal to the length of the film format diagonal. For 4×5 film, this is 162.6 mm, or 150 mm when rounded. Pictures made with normal lenses have a perspective that is normal-looking to most people. However, for many types of subject matter, a wider field of view is required, and for this you need a wide-angle lens having a shorter focal length. Wide-angle lenses are very popular for use on large-format view cameras and field cameras. They are almost as popular as normal lenses.

21.1 Hypergon

In 1900, Emil von Höegh at Goerz (the same man who designed the Dagor) designed what is still perhaps the ultimate in wide-angle camera lenses. It was called the Hypergon, an appropriate name. On a flat photographic plate or film, it could image without distortion a huge object field about 136 ($\pm$68) degrees wide. Figure 21.1(a) is the layout of a Hypergon lens itself. Figure 21.1(b) is a similar layout but with the image surface included to show the extreme ray angles.

The Hypergon consists of two extreme-meniscus singlet lenses placed symmetrically about a central stop. There is no attempt to correct the longitudinal chromatic aberration or spherical aberration, so the lens must be used at a slow *f*-number. In the present case, maximum opening is $f/16$. The lens in this example is also designed for a different format than earlier examples. It is intended for use with an 8×10 film and to form a round image area about 190 mm in diameter covering most of the middle of the picture. Focal length is 40 mm, and the object is at infinity.

Figure 21.1(c) is the spot diagram for 0, 0.5, 0.8, and 1.0 of the $\pm$68 degree field. It has been evaluated using the five panchromatic wavelengths, 0.420, 0.450, 0.500, 0.570, and 0.660 μm, all weighted equally. The spots are quite small, even without chromatic or spherical correction. The main aberrations on-axis are the remaining chromatic and spherical aberrations as balanced by some paraxial defocus (refocus). Off-axis, these aberrations are augmented by some lateral color and oblique spherical. All across the field, distortion is vanishing small; at the edge of the field, it is just +0.13%.

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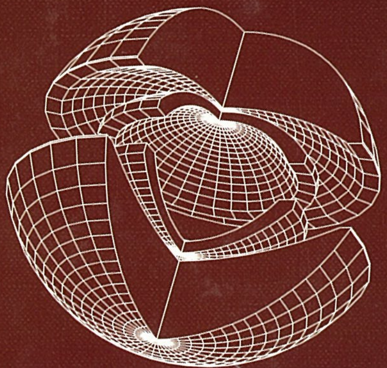
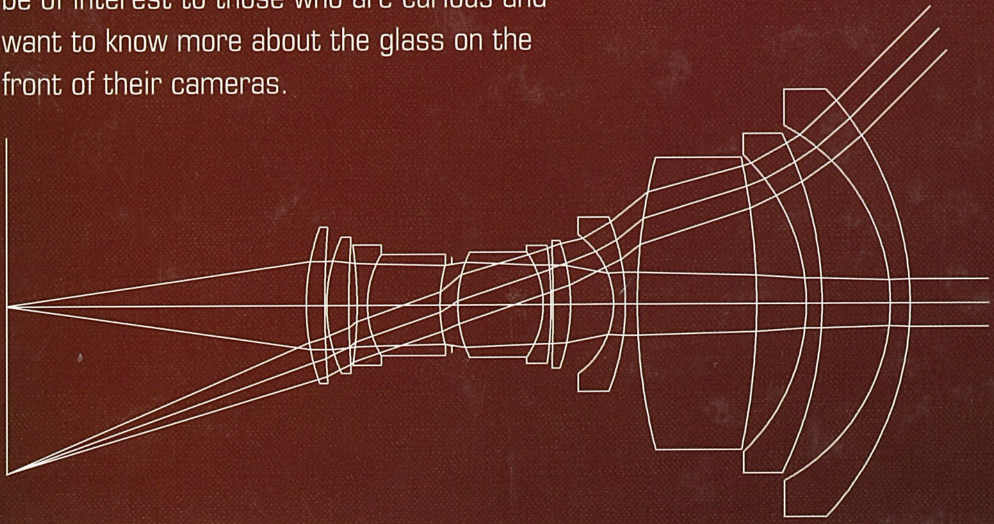


This book is an exploration and appreciation of cameras and their optics, covering all major lens types from the earliest to the most recent—including those roving the surface of Mars. A recurrent theme of this book is that lens types invented in the 19th century are just as useful in the 21st century. Another continuing theme is the impact of the digital revolution and the use of imaging in radically new circumstances. This book should be of interest to those who are curious and want to know more about the glass on the front of their cameras.



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Used, Very Good

SPIE Press
. Box 10
llingham, WA 98227-0010

BN: 0-8194-6093-1
IE Vol. No.: PM158

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